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Continuous heat processing

S.P. Emond, Campden & Chorleywood Food Research Association, Chipping Campden

3.1 Introduction

An improvement in quality was one of the main driving forces behind the development of continuous heat processes. Liquid and semi-liquid products such as milks, juices and sauces suffered from overprocessing in the traditional low temperature–long time of in-container or batch processing. Caramelised flavours, poor colour retention and a lack of a reproducible product were all problems associated with products processed by batch methods. Improving quality whilst maintaining product safety was the main aim for those developing continuous processing approaches.

The achievement of safe products by thermal processing is based upon the theory behind the destruction of microorganisms. Products must be heated to a set temperature for a set time in order to achieve a commercially sterile product. For continuous heat processing, also called continuous flow processing, the product is thermally processed before being placed into an appropriate container, on a continuous basis through a heat exchange plant. Heat exchange apparatus will be used for both the heating and cooling (if required) phase of the process.

In a continuous system the foods under consideration are liquid or semi-liquid products, which may be pumped through a system, heated and cooled whilst continuously flowing down the processing line. A wide range of products are processed by this method, either as the main process to achieve a safe product (as in Ultra Heat Treated or Ultra High Temperature (UHT) processing) or as a step within a further process.

Continuous heat processing is not a new technology and several good texts exist which give background to the developments through the years in this area.
This chapter will review the current status within processing equipment and highlight the developments which have been made in order to take into account the processor’s requirements for safe, reproducible systems which will ensure a safe product, maintain product quality and also maximise process efficiency.

The three main types of process that are suitable for continuous flow processing are, aseptic systems (high and low acid), hot fill systems and pasteurisation processes. Aseptically packed products are processed at temperatures that will render the product commercially sterile. High acid products such as juices can be processed at pasteurisation temperatures to destroy the microorganisms that can cause the spoilage of the product; these are then rapidly cooled (to reduce losses of volatiles within the product) and filled into a pre-sterilised pack under sterile conditions. Low acid products will undergo the same principle, however the temperatures employed are much higher to ensure no survival of pathogenic bacteria. The temperatures used within a UHT system for low acid products are usually in the range 125°C to 145°C, so allowing for much shorter holding times and promoting a higher quality product. Continuous flow processing systems can also be used in hot fill processes for high acid products that would otherwise lose product quality through slow cooling methods. High acid sauces, purées and chutneys can benefit from a continuous process by heating the product to pasteurisation temperatures and then filling directly into suitable containers, using the heat of the product to decontaminate the packaging. This method allows for a much quicker throughput than a typical batch process would offer. The final heating method for this type of system is pasteurisation of low acid products that will then be cooled and held under chilled conditions (e.g. pasteurised milk, juices and soups). This processing step extends the shelf-life and ensures a safe product. The product must be chilled to maintain its safety and quality throughout the shelf-life. Shelf-lives of up to ten days can be achieved for some products.

There are two main options open to a food manufacturer considering a continuous heat process, to process by indirect method, or by direct method. Indirect heating involves a heat transfer surface between the product and the heating media. Direct heating occurs where the product and heating media are in direct contact. Figure 3.1 illustrates the main options open to a processor. Another established continuous heating method available is Ohmic heating. This will be discussed in Chapter 12.

3.2 Indirect heating

Indirect heating methods rely on having a heat transfer surface between the product and the heating media. There are three main types of indirect heating system: plate heat exchangers, tubular heat exchangers and scraped surface heat exchangers. Each system has benefits and drawbacks depending on the product requiring processing and each has been adapted since the advent of these
systems to process a wider range of products and enabling the systems to compete directly.

3.2.1 Plate heat exchangers
Plate heat exchangers are a well-established method for processing homogenous products of low viscosity, making them ideal for use within dairies. Plate heat exchangers consist of a series of plates connected on a frame. The product and heating (or cooling media) flow in alternate channels in thin layers to provide good heat transfer conditions (Fig. 3.2). The plates are sealed by elastic sealing gaskets cemented into a perforated groove. Generally the plates are of polished stainless steel of 0.5–1.25 mm in thickness separated by 3–6 mm. The surface of the plates is usually corrugated in order to increase the area available for heat transfer and enhance the turbulence present in the system, resulting in a high thermal efficiency. Thermal regeneration can lower energy costs substantially. The narrow gaps mean that the units are best suited to low viscosity homogenous products. Attempts to process particulate products (e.g. fruit juice cells) may result in blocked channels and eventually blown plates due to the pressure imbalance between product and media sides of the plates. For this reason only products with less than 10% cell content are normally recommended when processing with plate heat exchangers.

The design of the plates can vary from supplier to supplier, each having different designs to maximise process efficiency and ensure product safety. Plates can be product specific. The corrugations that are present in plates are usually of a chevron or herringbone design in order to develop a turbulent flow through the plate as it passes through the plate pack (so increasing heat transfer). As the plates are assembled, the herringbone pattern is usually alternated, with the chevrons going up on one plate and down on the next, creating the channels through which the product can flow. The thickness of the plates will vary from
type to type, depending on the working pressure expected from the plates, but these can also be of thin gauge material which will ensure a high heat transfer. The design of the pattern on the plates in most cases allows for support of the whole plate pack, the plates are touching a designated point to ensure that the strength within the system is maintained but also the ease of cleanability is taken into account. The plates may also have larger spaces between, which will allow small particles to be processed in the system.

A further development in this area has been with the double-separation plate, which is designed for highest security, stopping contamination between the heating media and the processed product. The design is similar to a traditional plate heat exchanger but plate pairs are mounted together and are welded at the

Fig. 3.2 Flow through a plate heat exchanger (courtesy of Tetra Pak).
product ports. As the pairs are mounted together, this forms the channels through which the product flows and these are sealed together by an elastomeric gasket. Because of this design, if the system does suffer a gasket failure, the leak will be detected externally and action may be taken. This high level of security makes it ideal for high security operations such as in the pharmaceutical industry.

The design used on the plates may also take into account the level of fouling that will occur throughout the process. This is usually the limiting factor in production times and the longer a plant can run for, the less downtime costs there are for the process. The plates should also be designed to be cleaned in place, however, in some cases or during planned maintenance, the plates may have to be dismantled from the frame and cleaned and serviced by hand.

The application of the heat exchanger will determine the type of frame that should be used to hold the plates together. In the food industry (for food applications) the frame would normally be hygienically designed either being of solid stainless steel or completely clad in stainless steel. In industrial applications a mild steel frame would be sufficient for the heating of cleaning chemicals or media heating. The plates hang on the frame and are held together by a series of compression bolts which are tightened depending on plate size, thickness and number of plates. In some cases the heat exchangers will be modular, therefore allowing for easy extension of the plate pack, or changing for new applications. The advent of the hanging frame has enabled servicing and inspection, a much easier process than with the early frames where the plates had to be removed one by one.

The gaskets that are used to hold the plates together can be either cemented into place, or can be clipped into place. For ease of service, the clip on gaskets ensure that downtime is kept to a minimum whilst still ensuring that the hygienic barrier is maintained. The clips usually work by having two prongs which sit in the gap between two plates; in this way, in combination with the hanging plates, any changes in gasket can be carried out in situ.

Plate heat exchangers were traditionally used for pasteurisation processes and have been adapted to withstand the higher temperatures and pressures required for UHT processes. The main difficulty with plate heat exchangers was their tendency to foul followed by inefficient cleaning in place. A build-up of such debris in the streams in the system may ultimately lead to the product being understerilised leading to product spoilage or an unsterile product. The manufacturers of such systems are designing the plates in such a way as to make them suitable for cleaning in place. Producers using these systems should have planned preventative maintenance schemes in place to ensure that there is scheduled servicing and cleaning of the machines before this situation occurs.

One of the main advantages of plate heat exchangers is in the regeneration of energy used in the system. Product will pass through three sections in a plate heat exchanger. The first section will be a regeneration section where the incoming product will be heated by the outgoing hot product. The product will then enter the main heating section with the heating media on one side, which could be steam, but would more likely be a steam/water mixture (to try and
reduce the level of fouling that will occur on the surface of the plates) to take the product temperature up to process temperature. The final section that the product will pass through is the regeneration zone, this time as the outgoing hot product giving up its energy to the incoming product and so reducing the amount of cooling capability required by the system.

Preventative maintenance should take into account plate check for pinholes to ensure that there is no possibility for cross-contamination. Although the regeneration system ensures heat regeneration of over 90%, having a sterile product on one side of a plate and unsterile product on the other can cause problems of cross-contamination or re-infection. To try and reduce the possibility of contamination the regeneration system should be run so that the pressure on the sterilised product side is higher than that on the unsterilised side. It is for this reason that it is very important for such systems to have a sensitive, accurate pressure controller/recorder.

3.2.2 Tubular heat exchangers

Tubular heat exchangers will process a variety of products from low viscosity product such as those processed on the plate packs, but can also handle products of higher viscosity that may contain particulates such as soups and sauces.

In tubular heat exchangers product is pumped through a tube or multiple tubes, which are fixed inside a larger tube. In the space between the two tubes, heating or cooling media is pumped in counterflow to the product, maximising heat exchange efficiency. The mechanical strength of these tubes allows them to operate at high temperatures and pressures. Turbulence is achieved in the tubes by the velocity of the product and also by the presence of a corrugated surface to improve heat transfer efficiency. The amount of corrugation can be varied for compatibility between product and plant. A more angled corrugation can introduce turbulence without high velocity in low viscosity fluids such as water, juices and dairy products. Smoother corrugations which have more gradual angles and can impart a twist or turning motion, offer gentler handling of particulate and higher viscosity products. The more angled corrugations fill with such products and can reduce the efficiency of the exchanger.

The simplest design for tubular heat exchangers is the monotube, basically a tube held within a tube. Figure 3.3 shows the basic design for a monotube. The product flows through the central tube and is surrounded by the outer tube, which contains the heating or cooling media. This design is the most frequently used system for processing particulate products as there are few problems with the particulate matter blocking the tubes and so causing processing problems and pressure build-up. As the heating media surround the product, this type of system allows for very gentle heating of particulate products.

A more complex design, the concentric tubular heat exchanger is generally a single pass shell and tube exchanger with the product flowing through the gap between two heating (or cooling) media channels. The tubes tend to be smooth reducing the pressure drop that can occur when processing viscous products.
Concentric tubes have a single channel design where product flows through a tube which is surrounded by a second jacketed tube containing the heating (or cooling) media. Through the centre of the product tube is a further tube which also has the heating or cooling media flowing through it. In this way the product is surrounded by the media thus giving two heat transfer surfaces allowing for a more efficient heat transfer. As there is generally only one tube for the product to flow down this makes the plant easier to clean and to sterilise. Having a minimal effect on the flow patterns of the product, a uniform product quality for viscous products such as fruit purées, concentrates and sauces, such as mustard and mayonnaise can be achieved. The gap for the product flow can be designed depending on the application, giving wider gaps for products containing particulates.

A third design for tubular heat exchangers is the multitube system (Fig. 3.4). This can be anything from two to several parallel tubes, through which the product flows, surrounded by a casing which contains the heating media allowing the heating media to be between and around each tube. The tubes can be corrugated or smooth depending on the level of turbulence and heat transfer efficiency required. The models tend to be modular in that the heat exchangers can be put in series depending on the level of heat energy required to achieve the processing temperature. This design of heat exchanger can work at high temperatures (approximately 160°C) and pressures (approximately 6 mPa).

A variation on the multitube is the multichannel, consisting of several tubes in tubes allowing the heating media to flow either side of the product channel. This type of set-up allows for a very large heat transfer surface and therefore high thermal efficiency. This design also allows for heat recovery in the form of
product to product heating or cooling, as is achieved in plate heat exchangers. This design is based on narrow channels and is ideal for low viscosity products such as fruit juices.

There are several advantages for the processor using tubular heat exchangers. Designs are available to produce a wide product range. They are able to produce particulate product up to 12 mm and maintain the particle integrity and quality throughout the process. One of the main advantages though, is in the very simple designs, which cut down on maintenance costs and downtime.

One of the disadvantages with tubular heat exchangers is the tendency to form thermal cracks, due to the changes in temperature that occur in this type of process having hot product on one side of the tube and cold product or media on the other. To overcome this a floating end design may be used; this allows the internal tube bundle to move slightly within the outer shell, as they are not welded together (as in other designs). The floating end configuration also allows for changes in the tube configuration, allowing monotubes to be replaced by multitubes if a multipurpose system is required (e.g. in pilot scale or research units).

Tubular heat exchangers can also suffer very high pressure drops in the system (due to the long pipe lengths used in the systems) and this can lead to practical processing problems and issues with recontamination. For example, if the processor is processing a fruit purée at the pasteurisation temperature 95°C, the product will flow easily down the pipe, the viscosity of the product being much lower than at ambient temperatures. When the product is cooled the viscosity will rise again and cause a large pressure build-up in the system. It is

Fig. 3.4 Typical multitube design (courtesy of Tetra Pak).
for this reason that the pump used in the system must be well designed and able
to stand large pressure changes to ensure that blowback does not occur.

Tubular heat exchangers can also suffer from fouling and burn on. As the
tubes tend to be long, the processor does not have the ability to open and inspect
the plant after processing or cleaning so any fouling problems that can occur
must be understood and strictly monitored. Finally, though regeneration is
possible (currently for low viscosity products only), the maximum that can
usually be achieved is 70–75%.

### 3.2.3 Scrapped surface heat exchangers

A more complex design than the plate or tubular heat exchanger, the scrapped
surface heat exchanger offers a way of processing highly viscous product
containing particles that traditionally have been processed by the slower, batch
operations and enables a higher quality, repeatable product to be produced. The
basic design consists of a large tube in a tube (similar to the simple monotubes)
with the heating or cooling media on the outer shell. The central processing tube
contains a shaft which is connected to a motor and is supported by bearings at
either end. The shaft has blades attached, which are designed to scrape the
heating surface of the tube as the motor activates the rotation of the shaft. This
design is ideal for viscous products as the rotation causes turbulence within the
heating chamber, so increasing the heat transfer into the product and second, the
blades scraping on the heating surface reduce the build-up of fouling that can
occur with such products. Figure 3.5 outlines the main structure of scrapped
surface heat exchangers.

The shell of the heating tube can be chrome plated nickel (due to the high
thermal conductivity that it offers), stainless steel, bimetallic or chromed
stainless steel, depending on the application for which it is to be used. The shell
is usually of a standard diameter and manufacturers offer a range of central
shafts (or rotors) for a specific set of conditions to optimise processing. A
smaller diameter rotor will give a larger clearance within the heating chamber,
therefore allowing for the processing of products with larger particles and also
allow for a longer residence time in the heating unit. A larger diameter rotor will
minimise the heating channel therefore minimising the residence time but
allowing a more efficient heat transfer to occur. This design would be more
appropriate for lower viscosity products with only small particles.

Each rotor contains a set of blades and there are again several choices for the
processor depending on application. The material of the blade should be
compatible with the material of the shell of the heating tube. The scraper blades
should not cause wearing of the outer shell (for example if stainless steel blades
were used with a stainless steel shell) as this can cause damage to the heat
exchanger, allow for foreign bodies within the product and make the plant
difficult to clean. Manufacturers offer a wide range of materials such as durable
plastics (that withstand operating temperatures and conditions) which are a good
choice as they minimise the damage that can be done to the heat exchanger.
Stainless steel blades are also available for some specialist operations. The blades are attached to the rotor in different ways; the first is a ‘floating’ configuration, which enables blades to be easily attached to the rotor. As the rotor rotates through the product the blades scrape at the heating surface throughout the chamber. For very viscous products, some manufacturers offer different designs. The oval tube unit combines an oval shell containing a round rotor. By using this format the blade angle changes as the shaft rotates with product forced out from under the blade as the angle closes and moves under the blade as the angle opens. This method stops any mass movement that may occur in very viscous product as the shaft rotates. The second design is a spring-loaded
blade which enables blade contact with the heating surface at slower rotation speeds (50 rpm).

A different available design is a Multiscrape unit. Using multiple tubes within one shell, the scraper blades are mounted along a reciprocating piston. This reciprocating action enables efficient heat transfer into the product with minimal product damage. The rotor is sealed at each end by a rotary mechanical seal which is steam flushed to provide an aseptic seal (where necessary).

The heating or cooling media for scraped surface heat exchangers can be brine, water, steam, freon and in some cases, oil, which can then achieve temperatures of up to 315°C. Scraped surface heat exchangers can be installed in either the vertical plane or the horizontal plane. The vertical format can save floor space depending on plant design and so may be more advantageous in plants where there is little available space. Vertical designs now incorporate hydraulic units for the removal of the central shafts for servicing operations which makes for rapid inspection and maintenance. The vertical design also has a further advantage in that as the product enters the heating chamber from the base and travels upwards to the exit, this allows for effective purging of any air that may be present in the chamber so ensuring efficient heat transfer through the system. The air in the heating chamber will be transferred to the holding tube. Therefore this should be angled to allow purging of the air ensuring the correct volume in the holding tube is maintained.

Horizontal scraped surface heat exchangers benefit from an equal loading on both bearings within the system (instead of all of the loading on the lower bearing as in the vertical designs). As the associated pipework within the system can be connected to either the front or the rear connectors, benefits can be made from having reduced pipework designed to optimise the system within the production plant.

The advantages of the scraped surface heat exchanger system are that it can process very viscous product with particles up to 15 mm³. The process allows for reduced burn on (which would occur with this type of product) allowing for longer production runs. A lower pressure drop is seen in this type of system therefore reducing the problems with leakage and re-infection during processing.

The main disadvantage of scraped surface systems is the cost, being expensive to set up and expensive to maintain in comparison with other types of exchanger. New blades and seals are required regularly, and bearings have to be replaced periodically. New tubes may also have to be replaced occasionally. More floor space is required for scraped surface plants than for other types of exchanger. Finally due to the high shear mixing that occurs during the process there can be damage to some fragile particles.

3.3 Direct heating

There are two main methods for heating product by direct methods: by injecting pressurised steam into product or by injecting product into steam (steam
infusion). Both systems work on the principle that as the steam comes into contact with the product it will condense and give up some latent heat so causing the product to heat up very quickly. Both methods give practically instantaneous heating, as opposed to the indirect methods or by the very slow batch or in-container methods. Figure 3.6 compares typical heating curves for products heated by direct, indirect and batch processes.

The basic principle for both systems is to pass the product from a balance tank to a preheating system, usually by a plate heat exchanger to 70–80°C (for a UHT process). After this the product will pass through the main product pump through to the steam injection or infusion system. After holding the product for the required amount of time, the product passes through a reducing valve into the cooler. The cooling mechanism for such systems must also be quick and must remove additional water which will have been added by the heating method. To achieve this the product is passed into a vacuum chamber which will be held at a specific pressure corresponding to the product temperature before heating so causing the product to instantaneously boil and drive off the excess fluid whilst reducing the temperature to the preheat temperature before injection. The products processed by this method are then usually homogenised before cooling by indirect methods to ambient or chilled temperatures by indirect heat exchange (tube or plate).

3.3.1 Steam injection
Steam injection is most suitable for low viscosity, homogenous products such as milk and juices. There are many different types of steam injector available, with probably the most varied designs of all the heat exchangers. There are both static and dynamic injectors and the methods of introducing steam into the product are
aimed to heat the product as quickly as possible, to minimise any possible fouling by indirect heating methods (that is, from the surface of the injector itself) and to maximise the length of production run that can be carried out by the processor. The first requirement is thought to be maximised by the rapid condensation of the steam so rapidly heating the product. The product must be maintained at high pressure to prevent boiling at the injector; this is achieved by having a sufficient backpressure valve in the line before the injector system. The heating is also maximised by ensuring that the steam has good access to the product if the steam is introduced as small bubbles, or as a thin sheet. Although fouling is less of a problem in direct systems than indirect systems, there are still problems seen when the injector is poorly designed. As the steam will be injected through a nozzle or system of orifices, if this is not kept separate from the product the injector system will start to heat the product indirectly from the surface of the nozzle. This will cause fouling at the surface of the injector and therefore reduce the steam flow, so reducing the efficiency of the heating. To overcome this, manufacturers have designed systems that have the product entering the heating zone at right angles to the injector; this keeps the product away from the injector head and reduces fouling. After heating, the product passes through a reducing valve before entering the flash vacuum cooler which is held at a pressure suitable to cause the product to boil and drive off the added water from the steam injection. Control of the pressure in this system is needed for two reasons. First, this is to ensure that the correct amount of water is driven off, and second, that any undesirable volatile odours that may have developed during the injection process are removed. The flash vacuum chamber does bring its own problems however, as operating this at pressures lower than atmospheric pressure may allow contaminants to be sucked into the chamber. In order to reduce this, aseptic systems apply steam barriers to connecting joints moving seals and valves so that any material that may be sucked in will be sterilised before re-infecting both plant and product.

Steam injection can be quite damaging to products due to the aggressive method of heating taking place. The rapid condensation of the steam causes changes in pressure in the liquid. In milk products this is thought to break down homogenisation of the product and can cause the formation of casein aggregates giving a chalky mouthfeel. In order to reduce this, it is necessary after direct steam injection to homogenise (aseptically) such products.

3.3.2 Steam infusion
Steam infusers were designed to give a gentler process than that achieved by steam injection. Suitable for the same types of product, infusion systems can also be modified to handle small particles (such as cells in juices). The basis for this method is to introduce preheated product into a chamber containing steam at the temperature required for sterilisation. The steam chamber is usually a pressure vessel with a conical-shaped base through which the heated product falls into the holding section. Different types of infusion systems are available.
and can be designed to allow for the direct processing of products containing small particulates. Other systems have varying numbers of diffusion holes through which the product is passed before entering the infusion chamber; the holes can be closed off depending on the heating capacity required by the plant. One of the main areas that must be strictly controlled within the infusion system is the holding period between heating and cooling. As the product, once heated, falls to the base of the pressurised vessel, the amount of time taken to travel to the cooler is dependent on level controllers which are connected to the product feed pump to ensure that a sufficient quantity of product is entering into the chamber but is also leaving so ensuring a sufficient holding period and reduced overheating of the product. A further problem with infusion systems is that on entering the heating chamber any dissolved gases in the product will leave the product (as the solubility of gases is lower at sterilisation than at atmospheric temperatures), which cause the mixture in the heating chamber to change from saturated steam to a steam/air mixture. This can have an effect on the efficiency of the heating and to overcome this very often the steam pressure in the system must be increased gradually to ensure the process temperature can be achieved.

For both steam injection and infusion systems one critical part of the process is the steam quality. As the product and steam come into direct contact the steam must be of culinary standard. In the UK any producers should ensure that the steam adheres to the Food Safety (General Food Hygiene) Regulations 1995, specifically the requirement that any steam that comes into direct contact with food should be produced from potable water. Potable water means water which at the time of supply is or was not likely in a given case to affect adversely the wholesomeness of a particular foodstuff in its finished form. The steam should be dry saturated, oil free and should not contain volatile substances that can be carried from the steam into the product. The steam lines associated with direct heating systems should be stainless steel to prevent rust build-up and should also be filtered to remove any particulate matter.

3.4 Holding section

The holding section in a continuous system is the part of the plant where the product receives the cook and sufficient destruction of microorganisms to ensure that a commercially sterile and hence safe product is achieved. Usually a series of pipes and bends of known volume, product flows through the holding section at a known flow rate which allows the holding time from the entrance to the exit of the section to be determined.

Temperatures in UHT continuous flow systems are much higher than those used for traditional in-container processing. Temperatures in the range 125°C–130°C are typical and temperature in some exchangers can be greater than 145°C. For this reason the holding times that are considered in continuous flow processing tend to be much shorter. As these times are much shorter, strict control is needed to ensure the correct time temperature regime is given to
products as any deviation at high temperature can have a significant effect on the commercial sterility of the product.

The product is held at constant temperature (as set by the controller) and held for a time (dictated by the length of the holding section and flow characteristics of the product). To ensure that worst case conditions are taken into account when calculating the time for which the product is held, it is necessary to know something of the product flow characteristics. When assessing the flow behaviour of a fluid, the physical properties of that fluid must be known, including density, specific gravity, temperature and apparent viscosity. From this data the processor can calculate the Reynolds number (Re), a dimensionless number, which characterises the flow. This is calculated by the following equation:

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Re = \frac{\text{fluid density (kg m}^{-3}\text{)} \times \text{pipe diameter (m)} \times \text{fluid velocity (ms}^{-1}\text{)}}{\text{fluid viscosity (Pa s)}}
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In general if the Reynolds number calculates to be less than 2100, the flow is considered to be laminar, if between 2100 and 10 000, the flow is transitional and if greater than 10 000, the flow is turbulent.

When flow is laminar, the calculations are based on the fastest part of the flow (the centre) which is travelling twice as fast as the product, which is against the pipe wall. If the holding time is calculated on the mean velocity this would mean that the product at the centre only received half of the process required. For example, if the mean flow rate is 10 litres per minute and the volume of the holding section is 10 litres, the mean holding time would be 1 minute. However, the holding time would need to be doubled to 2 minutes to take into account the fastest moving fluid at the centre of the pipe to ensure that this part of the fluid received a 1 minute hold. The true relationship between the fastest moving particle and the pipe mean velocity depends on many factors. For example, the frictional resistance to the flow of the inside pipe walls, the changing temperature across and along the holding tube and the flow (rheological) properties are all important factors.

Worst case scenarios for the holding section should also take into account particle sizes and quantities in the product. The size of particle that can be processed by continuous methods is limited by the time for conduction of heat to the centre of the particle. Usually for particulate product a laminar flow is assumed, where the particles may be flowing twice as fast as the mean flow. For modelling purposes, it should be assumed that the carrier fluid around the particle is static, because this will give the worst case heat transfer to the particle surface and therefore will underestimate the process delivered.

When monitoring the temperature within the holding section, temperature losses along the pipeline should be taken into account. For this reason, it is necessary to securely lag the holding section to ensure any heat losses are kept to a minimum. In particular, the temperature sensors should be well lagged. Typically the controller temperature is located at the entrance to the holding section; however several degrees can be lost as the product passes along it, and
this should be monitored and taken into account when calculating the lethality of the process.

The holding section should also be designed to avoid entrapment of air within the product by elevating the tube by a small angle. It may also be necessary to consider the use of in-line mixers for high viscosity products. The mixers should be placed into the line prior to temperature measurement at the holding tube exit, to ensure adequate mixing. In-line mixing should also be used to avoid channelling of product within the holding tube and several may be used in series if the tube is long or product viscosity is very high.

3.5 Future trends

Continuous heat processing is an economical way to produce large quantities of product ensuring safe, high quality reproducible products that were not feasible for all products when produced by traditional batch methods. Whether UHT processed and aseptically packed, or heated and hot-filled or chilled and kept under refrigerated conditions, this method of processing offers the food processor a flexible system.

Plate heat exchangers offer a very well-established method for processing low viscosity homogenous products. Few developments are occurring in this area. Manufacturers of such equipment are offering easier to clean, quicker to service modules which enable a quick turnaround in terms of product downtime. Plate frames are designed to allow inspection to be carried out in place. The main development in this area is in the ability to produce product containing particulates with a reduced likelihood of blocking channels and again, reducing production time.

Developments for tubular heat exchangers are currently being actively researched. Although tubular heat exchangers are designed for some level of regeneration (particularly in concentric tube designs) this is limited to low viscosity products such as milks and juices. With the introduction in the UK of the Climate Change Levy in April 2001, food manufacturers are being asked to provide information on how they are conserving energy within their companies. Work, looking at the use of higher viscosity products such as sauces and purées for regeneration is being carried out currently with the aim of enabling equipment manufacturers to develop tubular heat exchangers that have the capability of using these higher viscosity products to preheat and cool product. The aim is to try and enable regeneration of up to 75% with this type of product.

Scraped surface heat exchangers are another well-established heating system in which few changes have occurred. Different materials are being used to aid heating and different plastics to try and extend the life of the blades between servicing. Companies such as Waukesha Cherry Burrell have updated their traditional horizontal processing equipment and have also introduced a vertical design, to compete directly with the other manufacturers. One development that has yet to be established commercially is the co-rotating disc scraped surface
heat exchanger (CDHE). Having a rotating heating surface and a stationary scraping device this system claims a high heat transfer capacity having heat transfer coefficients as high as 600 W/m²K when processing viscous fluids. The CDHE develops large zones of reverse flow in the processing chamber so improving mixing in the chamber and improving heat transfer. The work carried out by the University of Denmark outlines that when placing several processing chambers in series the CDHE has great potential specifically for UHT processing of foods showing pseudoplastic behaviour and also particulate foods.

Direct heating systems are also fairly static in terms of development being well-established systems. One of the areas where work is being carried out is in the use of direct systems for processing particulate matter. As already stated, infusion chambers can handle products containing small particles (such as juice cells) and further work is being carried out. Much needs to be understood about the method of heat transfer to the particles to ensure that on entry to the heating chamber the centre of the particle also achieves the required heat process so ensuring a safe product.

Other trends in this area do not refer to the traditional heating methods already discussed. There are other methods of continuous processing that are being used for both development and commercial purposes. Ohmic heating will be discussed in a later chapter and so is not discussed here.

### 3.6 Sources of further information and advice

#### 3.6.1 Equipment manufacturers

Further detailed information on specific designs of equipment is available from the manufacturers of the equipment. Major manufacturers that can offer help and advice on types of exchangers suitable for specific processes are:

**Tetra Pak Ltd., 1 Longwalk Road, Stockley Park, Uxbridge, Middlesex UB11 1DL, UK**
Tel: +44 (0) 870 442 6000
Fax: +44 (0) 870 442 6001
Website: www.tetrapak.com

**HRS Heat Exchangers Ltd., 10–12 Caxton Way, Watford Business Park, Watford, Hertfordshire WD1 8UA, UK**
Tel: +44 (0) 1923 232335
Fax: +44 (0) 1923 230266
Website: www.hrs.co.uk

**Waukesha Cherry Burrell, 2300 One First Union Center, 301 South College Street, Charlotte, NC 28202, USA**
Tel: +1 800 252 5200
Fax: +1 800 252 5012
Website: www.waukesha-cb.com
3.6.2 Trade associations
Trade associations offer advice on equipment and processors in this area. Further information can be found from:

The Processing and Packaging Manufacturers Association (PPMA), New Progress House, 34 Stafford Road, Wallingford, Surrey SM6 9AA, UK
Tel: +44 (0) 20 8773 8111
Fax: +44 (0) 20 8773 0022
Website: www.ppma.co.uk

The Dairy Trade Federation, 19 Cornwall Terrace, London NW1 4QP, UK
Tel: +44 (0) 20 7486 7244
Fax: +44 (0) 20 7487 4734

3.6.3 Professional bodies
Professional bodies offer information and publications in this area. Further information can be found from:

Institute of Food Science and Technology (IFST), 5 Cambridge Court, 210 Shepherds Bush Road, London W6 7NJ, UK
Tel: +44 (0) 20 7603 6316
Fax: +44 (0) 20 7602 9936
Website: www.ifst.org

Institute of Food Technology (IFT), 221 N. LaSalle Street, Ste. 300, Chicago IL 60601-1291, USA
Tel: +1 312 782 8424
Fax: +1 312 782 8348
Website: www.ift.org

3.6.4 Research associations and universities
Several universities and research associations can offer independent help and advice on processes and problems with processes. Further information can be found from:
3.6.5 Further reading

For further background reading the following texts offer specific advice and information in specialised areas:


3.7 References


